1.0 INTRODUCTION

1.1 Title of the candidate technology: LIGHT-WEIGHT FLEXIBLE SOLAR ARRAY (LFSA)

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1.3 Sponsoring IPDT: Modular and Multifunctional Systems (MAMS)

1.4 Category of proposed use: Category III Power Generation

1.5 Supplying organization: Phillips Lab & Lockheed Martin (LM)

1.6 Primary technology candidate contact: Suraj Rawal (LM)(303)-971-9378

1.7 Useful secondary contacts: Bernie Carpenter (LM) (Structures Lead) (303)-971-9128
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2.0 BACKGROUND

2.1 Characterize the candidate technology (What is it; how does it work; where does it go, etc.):

The candidate technology is basically a lightweight photovoltaic (PV) solar array system. The solar array will provide electrical power to the satellite. The uniqueness of this solar array is the use of copper indium diselinide/CuInSe2 (CIS) solar cells and shape memory alloys (SMA) for the hinge, deployment system, and (originally) the solar array drive.

2.2 How will the utilization of this technology enhance science in the 21st century?

PV solar arrays are the primary source of electrical power for geosyncronous and low earth orbiting satellites. This technology could provide higher power-to-weight ratios (specific energy), thus allowing a higher science payload mass fraction. Current solar array technologies provide specific energies in the range of 20-40 Watts/Kgm when the solar array deployment system and the solar array drive are considered. This technology could provide specific energies greater than 100 Watts/Kgm.

2.3 Why is this considered a revolutionary technology development?

Silicon (Si) and Gallium Arsenide on Germanium (GaAs/Ge) solar cells are technologies that involve cystal growth on a fragile wafer. The CIS thin film solar cell technology is vapor deposited on a flexible substrate which is substantially lighter than cells bonded to a rigid panel. The SMA also provides substantial weight savings over conventional hinges, deployment systems, and solar array drives. Therefore, a combination of these technologies provides significant improvement in the power-to-weight ratios. The shockless deployment could improve the spacecraft dynamics during deployment, and also is much safer to handle,integrate and test that conventional pyros. It is also resetable - electrically - so that the same device flies that is tested. The SMA deployment/hinge devices are significantly cheaper, simpler and therfore more reliable than current technology.

2.4 Why is a space flight necessary to validate this technology?

Ground qualification tests are ongoing for a number of parts that make up the entire solar array. However, total system performance (electrical and mechanical dynamics) can only be demonstrated under space flight conditions. It is extremely difficult and costly to verify the completed flexible solar array structures during ground testing both mechanically, electrically, and thermally. Spacecraft programs will not baseline this technology unless there has been some previous flight qualification of the technology. Specifically, the CIS must have a long term exposure to the space radiation, contamination and thermal environment. The SMA devices are very difficult to verify by analysis or 1-g testing and there is a low level of confidence in understanding this technology using these approaches.

It is necessary for the LFSA experiment to fly on the ram side of the spacecraft to maximize exposure of the solar cells to atomic oxygen. AO is a significant contributor to the degradation of thin films.

3.0 PROPOSED INTEGRATION & VALIDATION APPROACH

3.1 Describe your proposed approach to incorporating this candidate technology into the NMP/EO-1 flight and justify your categorization:

Approach

The proposed approach consists of the following:

- Do not fly a full CIS solar array. CIS has not yet been shown to perform after exposure to a low earth orbit space environment test program. Build a segment of CIS into a separate solar panel as an experiment mounted on the ram side of the S/C. This would be a panel only large enough for characterizing the CIS and the SMA release, deploy and deployed performance.

- Do not use the SMA gimbal which has not yet been shown to perform for the cycle life required for EO-1. (Agreed to by L-M)

- Utilize the SMA solar array deployment hinges and retention mechanism using an electric heater, rather than sun light, for activation. Provide a redundant HOP (high output parafin) actuator as an option on the pin puller deployment device if risk is still an issue at the end of Phase B. Provide a simple redundant spring device to hinges if risk is still an issue at the end of Phase B.

Phillips Lab will provide this solar panel system fully qualified to the spacecraft prime contractor. The array would be designed to interface directly to the ram surface of the spacecraft. The retention mechanisms would be designed to inteface to the S/C and solar array. An interface control document would be developed by the spacecraft prime contractor to define these interfaces to Phillips Lab / Lockheed Martin Astronautics (LMA). This solar panel would be provided by Phillips Lab for flight validation at zero delta costs to the EO-1 project.

These technologies are classified as Category III.

3.2 Describe the approach presently in the budget:

The current baseline is as follows:

- Gallium Arsenide on Germanium (GaAs/Ge) solar cells mounted on a rigid graphite composite substrate provided by SAI
- An Articulating Solar Array using a Schaffer drive and electronics
- Conventional Constraint and Pyro activated release system
- Conventional mechanical hinge and damper system

3.3 Describe how your proposed approach affects the current approach:

As an experiment, it will not affect the baseline.

3.4 Describe the interface with the spacecraft or the Advanced Land Imager (ALI):

The solar panel would have a mechanical bolt mount to the ram side of the S/C which would accomodate 2 SMA hinge/deployment devices. The solar panel would have a electrical connector interface to the S/C. The release mechanism would have mechanical bolt mount to the S/C.

3.5 Describe the impacts on the spacecraft or the ALI:

Cost Impact: An Interface Control Document (ICD) will have to be developed between the Solar panel and the S/C. The procurement costs for the spacecraft prime contractor to attain this technology from Phillips Lab will be a net zero delta cost including GSE for deployment testing.

Technical Impact: The center of mass and center of aerodynamic drag will change from the baseline. More jitter could be added to the S/C as a result of the flexible solar panel, especially when transitioning between eclipse and sun light. Due to the low mass nature of the experiment and its design, this is not expected to be a problem.

3.6 Describe your proposed approach to the integration and test of the candidate technology:

This technology would be as fully tested at the component level as possible (functional and envrionmental). The solar panel would be delivered to the spacecraft prime contractor fully tested and assembled. The release mechanism would be delivered to the spacecraft prime contractor fully tested. The release mechanism would be delivered prior to enviromental testing and integrated onto the S/C. The solar panel would be delivered to the S/C prior to vibration and acoustic testing at the S/C level. The solar panel would be deployed prior to vibration and acoustic testing and after testing. The solar panel would be tested again during final testing prior to shipment to the launch site. LMA has a suspension system that they would supply to the I&T facilities for g-negation deployment testing.

<u>Plans For Fully Testing The Arrays At LMA:</u>

a) Deployment:

To accomplish this LMA will conduct system level deployment tests of the assembled solar panel. An advantage of using SMA actuators is the capability to re-stow the array and repeat the deployment multiple times. LMA intends to use a simple gravity offload suspension to test deployment using separate test setups. This approach requires utilizing long, lightweight suspension wires to support the array in the two different test configurations. The Vertical Test Facility (VTF) of LMA's structures lab allows suspension lengths of 35 meters and has considerable experience with gravity offload on other programs requiring testing of solar panel deployment. At present LMA plans to test the panel attached to a spacecraft simulator. LMA believes that this facility is not sufficient to conduct these tests with the actual spacecraft. Assuming another facility exists for full scale testing, they would support at zero delta cost.

b) Acoustic Testing:

Vibration and acoustic testing is planned for the stowed solar panel system prior to delivery.

c) Solar panel Performance Testing:

LMA plans to conduct illumination and continuity tests following critical environmental tests. A key evaluation criteria is the specific power output in AMO under standard (28 C) temperature. Individual photovoltaic modules up to 6in. x 6in. will be tested in a new facility capable of evaluating these modules in AMO and AM1.5 insolation while monitoring temperature as the modules are heated or cooled. I-V and quantumn efficiency characteristics will be measured by sweeping in both directions. Modules as well as the complete solar panel will be tested in the large space chamber/solar simulation laboratory. Solar spot size of 16 ft dia. as well as 0.35 to 1.4 sun insolation can be realized.

3.7 Describe your proposed approach to operations in general and to validation in particular for the candidate technology:

The CIS segment would be monitored and trended by mission operations. Voltage, current, and temperature readings would be sampled at a sufficient rate to characterize the solar panel performance and degradation throughout each orbit over the mission.

The structural performance would be monitored during deployment with status switches and during orbital operations with LMA integrated accelerometer and ACS gyro output data.

Trend plots of the performance would be prepared on daily, weekly, and monthly basis. Psuedo telemetry characterization of power would also be trended. Minimum, maximum, and average values of telemetry would be trended. This data would be made available to GSFC and Phillips Lab for analysis. Degradation would be compared to the performance prediction models.

3.8 Describe the specific impacts on spacecraft resources:

See ICD for detailed impact on the spacecraft.

3.9 Describe how we would contracturally acquire the candidate technology:

Phillips Lab has indicated that they will provide this technology at zero delta costs to the EO-1 project. Phillips Lab would establish their own contract with Lockheed Martin Astronautics. Lockheed Martin Astronautics would deliver the solar panel to the government (Phillips Lab and GSFC) and the solar panel will be GFE to the spacecraft prime contractor.

3.10 Describe any facilities issues or special GSE or FSE:

A critical aspect of the solar panel system is the deployment action. In order to assure high reliability, deployment will be demonstrated using the actual flight hardware. To accomplish this LMA will conduct system level deployment tests of the assembled solar panel. An advantage of using SMA actuators is the capability to re-stow the panel and repeat the deployment multiple times. Due to the flexible nature of the panel all aspects of panel deployment cannot be tested simultaneously. A simple gravity offload suspension is planned to test primary and secondary deployment using separate test setups. This approach requires utilizing long, lightweight suspension wires to support the panel in the two different test configurations. The Vertical Test Facility (VTF) of LMA's structures lab allows suspension lengths of 35 meters and has considerable experience with gravity offload on other programs requiring testing of solar panel deployment. At present LMA plans to test the panel attached to a spacecraft simulator. This testing LMA is prepared to conduct at zero delta cost. LMA believes that their facility is not sufficient to conduct these tests with the actual spacecraft. Assuming another facility exists for full scale testing, LMA would support at zero delta cost.

The current/voltage characterization equipment required needs to be determined. The Large Area Pulsed Solar Simulators (LAPSS) used for characterizing solar panels is adequate for this solar panel.

4.0 AVAILABILITY

4.1 Identify the earliest date when an ETU or comparable demonstration hardware (and/or software) would be deliverable to the project:

No ETU proposed.

4.2 Identify the earliest date when flight hardware (and/or software) would be deliverable to the project:

April 1, 1998

5.0 RISK

5.1 Characterize the technical risk associated with this candidate technology. Identify specific risk mitigation approaches to the technical risk that you would recommend.

There is high risk associated with the CIS technology, thus Category III.

There is significant technical risk with the reliability of the SMA mechanisms to release and deploy the solar panel as required. LMA has an adequate analysis and testing program in place to determine this risk by the end of Phase B. Simple redundancy using conventional technology - a HOP with the release device, and a spring deployment device - would reduce the risk.

On-orbit hinge deployment can be assured is to place the transition temperature of the SMA above the max. environment temperature. Thermal gradients in this case would only change the amount of current required to cause the hinge to revert to austenite but no signigicant mechanical work generated. The heat flux would be nearly equilibrated under the influence of "external" environmental temperature gradients. Thus a certain amount of risk reduction can be achieved by thermal modelling and a design that accounts for these predictions.

There is significant technical risk that with the dynamics of the flexible solar panel, EO1 may not meet the payload pointing requirements. LMA has an adequate analysis and testing program in place to determine this risk by the end of Phase B.

5.2 Similarly, characterize the schedule risk associated with this candidate technology. Identify specific risk mitigation approaches to the schedule risk that you would recommend. Identify any schedule "trigger points" that represent decisions to shift to alternative development paths.

As a Category III, there is no schedule risk.

5.3 Lastly, characterize the budgetary risk associated with this candidate technology. Identify specific risk mitigation approaches to the budgetary risk that you would recommend. Identify the total budgetary reserve you would recommend to make the aggregate risk of incorporating this candidate technology acceptable.

Most of the budget risk is associated with the procurement interface costs to the spacecraft prime contractor. This assumes that Phillips Lab assumes all costs above the zero delta costs.

6.0 BUDGET

6.1 Determine the net cost to incorporate and validate the candidate technology by using a spreadsheet comparison between the budget distribution for the current approach and the candidate technology. Identify any cost-sharing with the supplier. Identify funding for fiscal years 1996 through 1999 and subdivide the entries into Development, Integration & Test , and Operations which includes the validation of the candidate technology. Be sure to include and highlight the cost of the risk mitigation approaches you recommended under Risk.

Funding provided to Phillips/Lockheed-Martin

No funding provided by the EO-1 Project. Outside funding provided to the Project as a separate financial analysis spreadsheet.

Funding provided to Swales

Funding for the Swales I&T of the LFSA is part of the spacecraft budget, $189K.

GSFC funding

GSFC Travel Costs	5 trips to LMA	5K*
GSFC Electrical Testing (J&T task)		40K
GSE for holding LFSA in Fixture		20K
Reserve		5K
TOTAL		70K

* divided up equally across the years

7.0 RECOMMENDED DISPOSITION

Justify the incorporation of this candidate technology on the NMP/EO-1flight. Weigh the benefits described in the Introduction against the accommodation impacts associated with budget, schedule, and overall risk. Is the NMP/EO-1 flight a suitable, cost-effective testbed for this candidate technology? How well does this candidate technology contribute to the most robust technology mission that we can afford?

Phillips Labís offer to pay all delta costs make this a cost-effective candidate. Additional costs are minimal.

The reliability of this technology to deploy as required will add risk to achieving the experiment objective but not to the mission objective. Providing simple redundancy and a thorough test program will significantly reduce the risk.

A jitter analysis has been completed on the LFSA using EO-1 model provided by Swales and LFSA model provided by Lockheed Martin. The LFSA is sufficiently lightweight that no significant impact to the instrument was found.

Recommend to carry to Phase C/D.